Quantum Phase Transitions

SoSe 24
Lukas Janssen

Coordinates

Mo 9:20 - 10:50 BZW/A120
Fr 9:20 - 10:50 SE2/201

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Website: http://tu-dresden.de/physik/qcm/lehre/qpt-ss24

Exam: oral exam as part of rigorosum/replacement (PhD students) or specialization "Theoretical physics" (MSc students) possible

Exam prerequisite (PVL, MSc students): written problem solutions, > 1/3 of points, presented in class

Ungraded assessment (PL, BSc students): written problem solutions, > 1/3 of points, presented in class

Content

Phase (a definition attempt): Equilibrium state of matter whose qualitative characteristics do not change upon small change of external parameters ("stable")

⇒ thermodynamic potential varies analytically

Phases are:

- characterized by symmetry of $S = \sum_j p_j |\psi_j\rangle\langle\psi_j|$ (density operator)
- separated by phase transitions

Phase transition: Point in parameter space at which equilibrium properties of a system change qualitatively ("unstable")

⇒ thermodynamic potential nonanalytic

Phase transitions can:

- be continuous or discontinuous
- occur at $T > 0$ ("thermal") or $T = 0$ ("quantum")

Quantum phase transition (QPT): Phase transition at $T = 0$, which occurs upon varying non-thermal control parameter (pressure, magnetic field, chemical composition, ...)

⇒ ground-state energy nonanalytic in control parameter

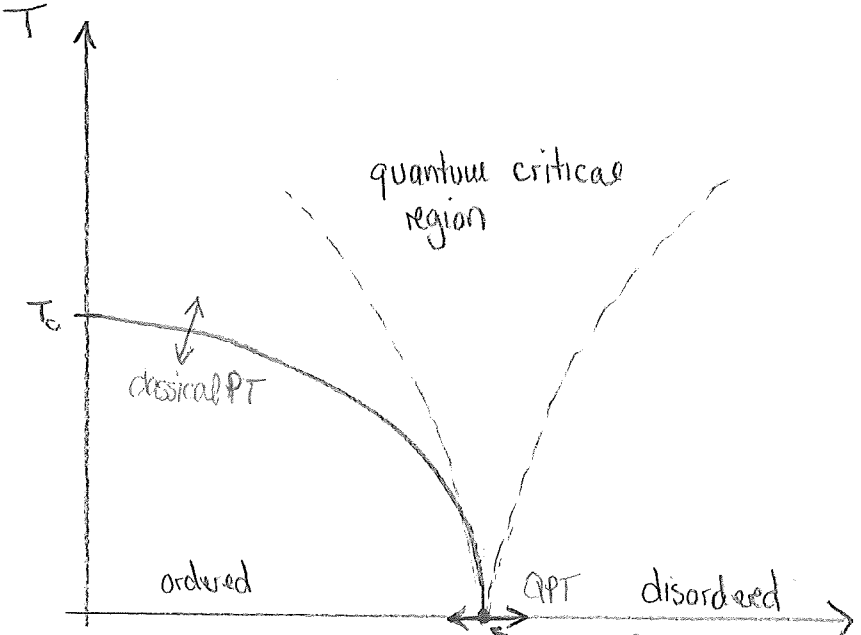
Remark: QPT apparently driven by "quantum fluctuations"

Disclaimer: $T = 0$ ⇒ state described by single phase-coherent (many-body) wavefunction

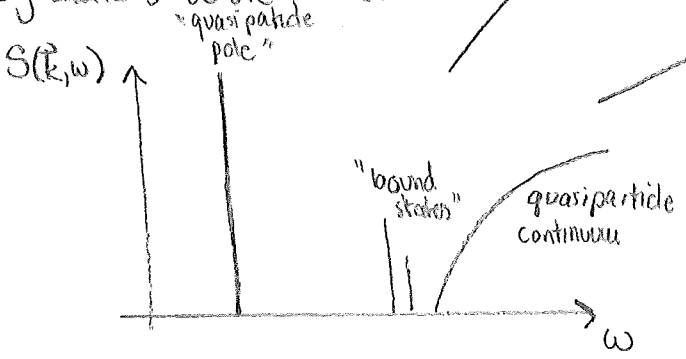
"fluctuations": deviations from a reference state (e.g., ordered magnet)

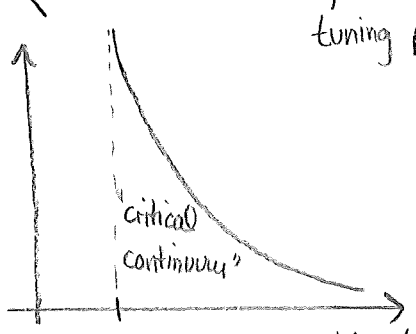
Experimental elevance:

Quantum phase diagram:



Dynamic structure factor:





e.g., Fermi liquid : $C_V \sim T$

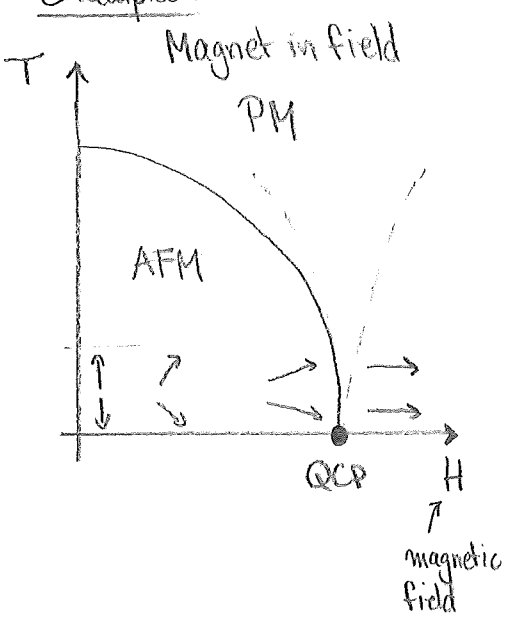
gapped magnet : $C_V \sim \frac{1}{T} e^{-\frac{\Delta}{k_B T}}$ (Δ: gap)

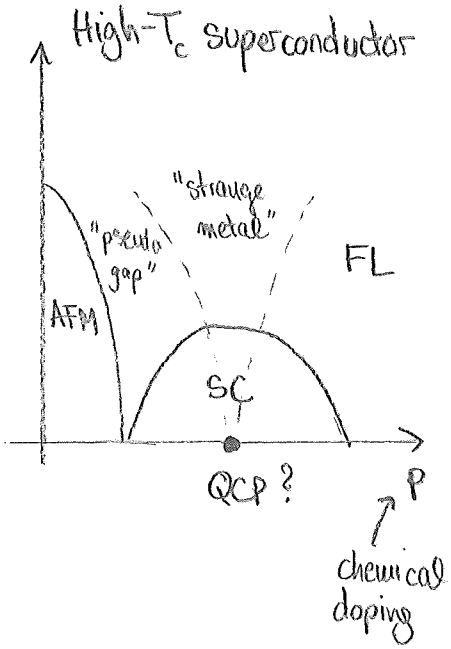
e.g., $C_V \sim T^{d/z}$ (d: dimension)

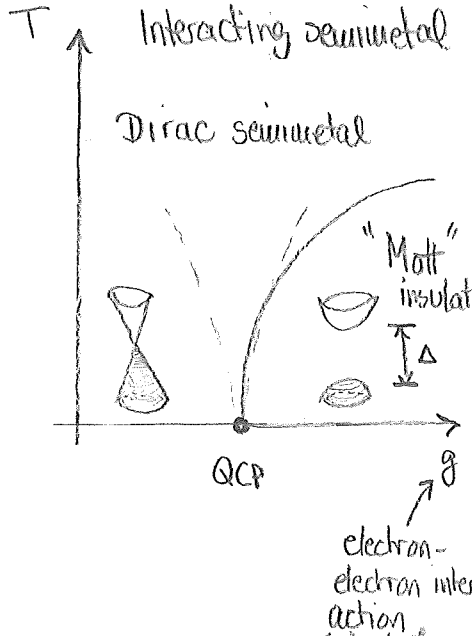
"dynamical critical exponent"

"novel state of matter"

Examples:







Other examples:

- disordered system ("Anderson transition")
- cold atoms on an optical lattice
- quark matter ("chiral symmetry breaking" in QCD)